STUDIES OF NIR DUST ABSORPTION FEATURES IN THE NUCLEI OF ACTIVE AND IRAS GALAXIES

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Abstract. We present the first survey of the 3.4μm hydrocarbon absorption feature in active and IRAS galaxies. Comparison of our data with galactic studies of this feature provides insight into the nature of dust grains around active nuclei, and holds the potential to improve our understanding of interstellar dust.

1. Introduction

One of the most exciting developments for understanding active galactic nuclei has been the development of unification theories in which the presence or absence of the broad permitted lines (*i.e.*type 1 or type 2 Seyfert class) is determined by the line of sight through a physically and geometrically thick obscuring torus of material which surrounds the active nucleus (*cf.* Antonucci 1993). There is a growing body of evidence that several type 2 Seyfert galaxies do indeed have hidden broad line regions. NGC1068 is an archetypal example of such a galaxy in which spectro-polarimetry has shown the broad line region in emission that is scattered into the line of sight by free electrons above and below the disk. There are now also a few direct detections of a broad line line region in Seyfert 2 galaxies (*e.g.*Goodrich *et al.* 1994), observed in IR lines which penetrate the dust. However, until now there has been little direct study of the nature of the obscuring material or its distribution. Roche *et al.* (1991) carried out a survey of the 10μm

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band in infrared bright galaxies and found that the spectra of AGN were either featureless or showed silicate absorption, while starforming galaxies showed strong PAH emission features.

The recent dramatic improvements in sensitivity and resolution of near-IR array spectrometers make extra-galactic observations of dust absorption features in the 3-5μm region feasible. To provide alternative diagnostics of obscuration in type 2 AGN and IRAS galaxies we have therefore begun a programme to study directly the dust and molecules. The 3.4 μm hydrocarbon absorption features, H_2O ice features (3.1 μm), CO absorption (4.6 μm and the silicate feature (9.7 μm) are all seen towards our galactic centre and have the potential to provide new information about the nature (e.g. composition, density) of the extinction in these galaxies. The 3.4 μm band is particularly important because it has been well studied in our galaxy. The shape of the feature has been shown to result from stretching modes of C-H in saturated aliphatic hydrocarbons, and Pendleton *et al.* (1994) have demonstrated that the carriers of this feature are widespread amongst the dust in our galaxy. The detection of this band in other galaxies also has the potential to increase our understanding of the grains in the ISM by extending the range of conditions in which the grains are observed. We present here the very first extra-galactic detections of the 3.4 μm band.

2. Observations

Spectra of the nuclei of a sample of about 12 galaxies covering at least 0.5μm centered at the redshifted wavelength of the 3.4μm feature were obtained in March 1994 and June 1995 at the United Kingdom Infra Red Telescope with the near-IR spectrograph CGS4 (Mountain *et al.* 1990). The galaxies were selected from a sample of all galaxies for which there was some evidence for a high degree of extinction to the nucleus, e.g. evidence for an obscured broad line region from optical polarisation measurements or near-IR spectroscopy, extremely red near- to mid- IR colours, a previous measurement of a silicate absorption feature in the 10μm band, etc., and which were estimated to be sufficiently bright to detect with CGS4 at 3-4μm from K, L or M band photometry. The sample includes nearby Seyferts and some ultra-luminous IRAS galaxies. Bright starburst galaxies have not been included as many are known from previous studies to have PAH emission features at 3.28μm (Moorwood 1986) which would make detection of the 3.4μm band more difficult.

In March 1994 the spectral resolution was $\sim$ 500, the spatial resolution was 3.1 x 3.1 arcsec, and the spectral coverage was achieved by observing several overlapping wavelength regions. By June 1995 a larger array provided more wavelength coverage with a spectral resolution of $\sim$ 800

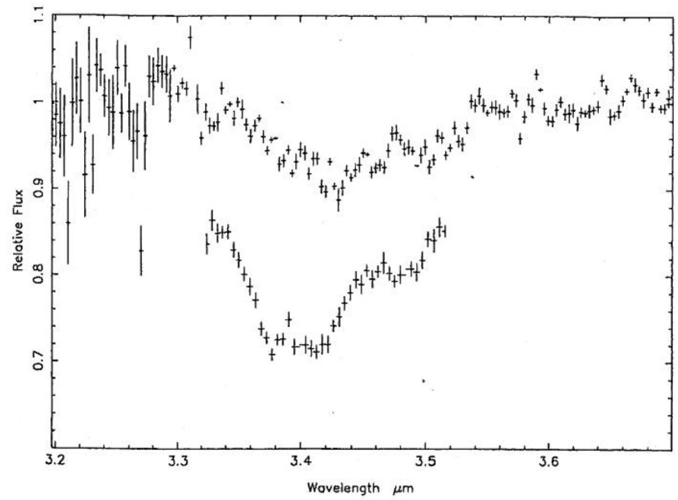

Figure 1. NGC1068 (top) compared with IRS6 (bottom)

and spatial resolution of 3 x 1.5 arcsec. Even the brightest galaxies we observed are 2-3 orders of magnitude fainter than the galactic sources in which the 3.4μm feature has been studied, and accurate sky subtraction at these wavelengths is essential. With a long slit spectrometer such as CGS4, subtraction of residual sky emission (after the usual IR technique of chopping, nodding and subtraction in pairs), may be achieved by fitting to the blank sky positions in the slit - a technique which greatly improves the reliability of weak features in extra-galactic sources. In addition, at least two independent observations of each galaxy were obtained. Wavelength calibration is accurate to better than 0.003μm across the spectra. The galaxy spectra were ratioed by F/G stellar spectra at the same mean airmass to remove atmospheric absorption. Repeated observations and spectra taken at overlapping wavelength regions were then merged to produce a final spectrum. Galaxies for which the independent spectra were not consistent and which indicate a sky subtraction problem will be re-observed. A linear continuum was fitted to data outside the absorption feature and removed.

Reduction of all the data from the survey has not yet been completed. Moreover, additional observations of some of the galaxies are required for a definitive result. The discussion in the following sections is based on the galaxies for which reduction and analysis of the spectra has been completed to date.

3. Results

The two best detections of the 3.4μm feature obtained to date are in the classic example of an obscured active nucleus, NGC1068 (Bridger *et al.* 1994), and in the ultraluminous IRAS galaxy, 08572+3915, which has

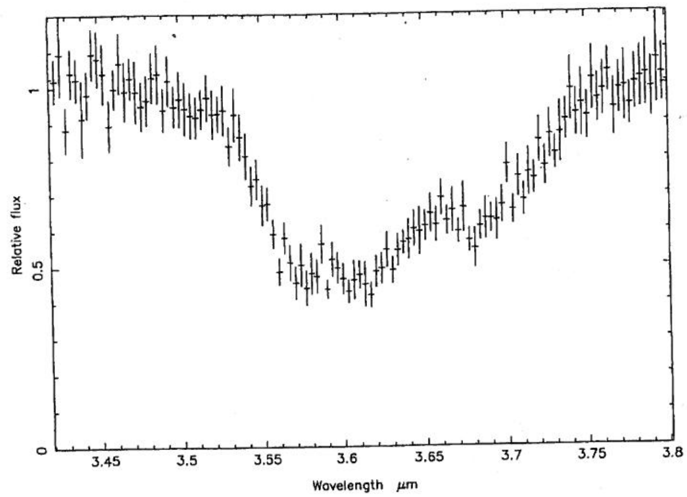

Figure 2. Spectrum of the 3.4μm absorption in IRAS 08572+3915

an unusually strong feature.

Figure 1 shows the spectrum of NGC1068 after the continuum has been ratioed out, along with a spectrum of the galactic centre source IRS6 (Pendleton *et al.* 1994) which is plotted on the same scale, but offset for clarity. The two spectra are remarkably similar. In particular the sub-peaks in the galactic spectra seen at 3.38, 3.42 and 3.48μm are clearly seen in the NGC1068 spectrum at 3.395, 3.43 and 3.50μ m consistent with the recession velocity, 1137 km/s, of NGC1068. In Figure 2 the spectrum of IRAS 08572+3915 at a redshift of 0.058 is shown after removal of the continuum. The sub-peaks of the galactic interstellar feature can again be seen, as expected at 3.57, 3.61 and 3.70μm. This feature is four times stronger than that seen towards IRS6, and is the deepest 3.4μm absorption ever measured.

Noisier detections of the absorption have also been obtained in Mkn463E and IRAS05189-25. The feature was not detected in NGC4418, while in Mkn231 a very weak feature may have been seen. Figure 3, a spectrum of IRAS05189-25, gives an indication of the more typical quality of 3.4μm spectra of galaxies, in which a weak absorption feature is seen against a noisy continuum. In IRAS05189-25, it is likely that both a 3.28μm PAH emission feature and the 3.4μm absorption have been detected. A summary of the results of our survey to date is given in Table 1.

4. Comparison of galactic and extra-galactic dust features

In NGC1068 and IRAS 08572+3915 the detailed shape of the 3.4μm absorption band is amazingly similar to that seen from the diffuse ISM in our galaxy. Indeed, as the figure in Pendleton (1996, this volume) comparing the

TABLE 1. Measurements of the 3.4μm absorption in galaxies.

Galaxy	Redshift	Optical Depth at 3.42μm band
NGC1068	0.003	0.1
IRAS08572+3915	0.058	0.5
Mkn463E	0.05	$\leq$ 0.05
NGC4418	0.007	No features
Mkn231	0.041	$\leq$ 0.02
IRAS23060+0505	0.173	No features
IRAS05189-25	0.043	0.05

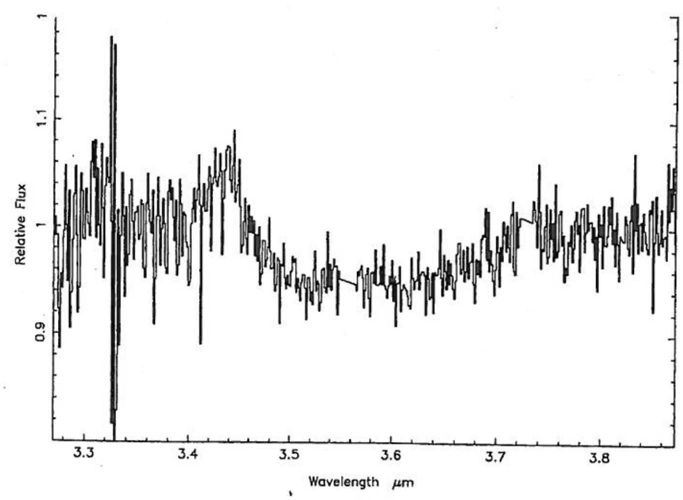

Figure 3. Spectrum of IRAS 05189-25

IRS6 spectrum with a de-redshifted plot of IRAS08572+3915 shows, even the relative strength of the 3.38 and 3.42μm sub-features is approximately the same, indicating that the extra-galactic dust has a similar CH_2-CH_3 ratio. The signal to noise ratios of the other detections of the absorption band are too low for a detailed comparison of shape and sub-features, but the general width is the same, suggesting that the same grains are present in these galaxies also. Pendleton *et al.* (1994) have argued that the organic component of the diffuse ISM is widespread and these detections extend that result to other galaxies.

The Seyfert galaxies in which we have detected the feature are almost face on, and it is extremely unlikely in these galaxies that the absorption arises from the diffuse ISM in the disk of the galaxy. It is more plausible that the absorption arises in the torus surrounding the active core. In both NGC1068 and Mkn 463E the optical depth of the 3.4μm feature is consistent with other estimates of the extinction in the circumnuclear torus, if the galactic relationship between $\tau_{3.4}$ and A_v in the ISM (Sandford *et al.* 1995) is valid for the obscuring torus. For NGC1068, $\tau_{3.4} \sim 0.09$, implies $A_v \sim 22$, consistent with $A_v \sim$ 20-25 derived by Bailey et al (1988) to account for the polarisation at 2.2μm. Since the extinction to the broad line region in NGC1068 is much higher than this, the best model is that the 3.4μm absorption is measuring the extinction through the edge of the torus to a region of warm dust emitting in the NIR (*cf.* Efstathiou et al 1996). For Mkn 463E $\tau_{3.4} \leq 0.05$, implies $A_v \leq 12$, consistent with $A_v \sim 10$, estimated from the direct detection of the broad line region in the near-IR in this galaxy (Goodrich *et al.* 1994).

In the two IRAS galaxies in which we have detected the feature the location of the dust is more uncertain. The higher redshift of these galaxies means that the slit includes a larger region of the surrounding galaxy. Moreover the galaxies have disturbed optical morphologies, with dust lanes crossing the nuclear regions (Sanders *et al.* 1988). In IRAS05189-25 the inclusion of near nuclear star-forming regions in our beam would explain the presence of both PAH emission and 3.4 μm absorption in the spectrum. A simple minded application of the galactic relationship between A_v and $\tau_{3.42}$ for IRAS 08572+3915 implies $A_v \sim 130$. Goldader *et al.* (1995) use $A_v \sim 38$ for the reddening of the 2.2μm continuum. The fact that the 3.4μm band is so strong in this galaxy may be an indication that, as may be the case in our galactic centre (Sandford *et al.* 1995), there are more carriers of the 3.4μm feature relative to other grains responsible for extinction.

Recent studies in our galaxy have shown a remarkable correlation between organic (optical depth at 3.4 μm) and silicate (optical depth at 9.7 μm) dust (Sandford *et al.* 1995). The distributions of the carriers of the two features are so similar that it has been suggested that these two components of the ISM may be coupled in the form of silicate-core, organic-mantle grains. (see the discussion in Pendleton 1996, for more details). Some of the galaxies in which we have measured the 3.4 μm band have measurements of the silicate feature obtained in similar apertures (Roche *et al.* 1984, Dudley, private communication). Table 2 gives the ratio of optical depths in the 3.4 and 9.7 μm bands for galaxies in our survey, which should be compared to the galactic value of 0.06 +/− 0.01.

There appears to be little correlation between the the depths of the Si-O and C-H bands for this small sample. The most striking demonstration of this is that we did not detect a 3.4 μm absorption band in NGC4418 which has one of the strongest silicate absorptions measured (Roche *et al.* 1986).

TABLE 2. Ratio of optical depths for organinc and silicate dust

Description 1	$\tau_{3.42}/\tau_{9.7}$
NGC1068	0.16
IRAS08572+3915	0.02
Mkn463E	$\leq$0.10
NGC4418	$\leq$ 0.03

It may be that the lack of correlation is an indication of real abundance differences between the carriers, perhaps due to more or different grain processing around the AGN in these galaxies. However, it is more likely to be due to geometrical effects in the distribution and temperature of the dust surrounding the AGN. Observations of normal galaxies and more detailed modelling in these galaxies will be required to clarify the interpretation of this result.

Spectra of galactic centre sources towards which the 3.4μm C-H absorption band is strong, also show a strong broad absorption from 2.9 to 3.23μm due to the O-H stretching band, which is attributed H_2O ices or water hydration in silicates. Sandford *et al.* (1991) show that the O-H and C-H features probably arise from independant carriers and that the O-H is associated with dense cloud material while the C-H material arises from the diffuse interstellar medium (DISM). We have not detected the O-H band in either NGC1068 or IRAS 08572+3915, the only two galaxies in which we have searched for it. This suggests that like the DISM, the dust in the central regions of these galaxies does not contain significant amounts of OH. If the O-H band in the galactic observations is largely due to water ices, the absence of such a feature in AGN may be a result of the substantially warmer dust temperatures.

5. Conclusions

We have presented the first survey of the 3.4 μm dust absorption band in external galaxies. These observations provide new insight into the nature of the dust in obscured AGN and IRAS galaxies. They also provide tantalising hints that dust properties may vary between galaxies. However, they are only the beginning of what will be possible for extra-galactic studies of dust. Detections of this feature in the ISM of normal spiral galaxies are just becoming possible. A few detections of the 3.4μm feature in normal galaxies are the key to improved understanding of the chemistry of grains in the ISM and in the circumnuclear dust discussed here. We also intend to obtain higher resolution, higher signal-to-noise comparisions of the detailed structure in the galactic and extra-galactic features. ISO spectra of these galaxies will provide a wealth of information about related features at wavelengths that are inaccessible from the ground. New mid-infrared spectrometers will soon provide better spatial and spectral resolution in the 10 and 20 μm bands, and enable a more detailed comparison of near and mid-IR dust features in external galaxies. Obtaining such data for a wide range of galaxies may provide crucial details of the destruction and survival of dust grains in galaxies.

6. Acknowledgements

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